Journal of Optoelectronics and Advanced Materials Vol. 3, No. 2, June 2001, p. 403 - 406

RESEMBLANCE OF LASER LIGHT AND ELECTRIC FIELD INFORMATION RECORDINGS ON CHALCOGENIDE GLASSY SEMICONDUCTORS

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It is shown that both the effect of laser pulses and electrical pulses, have a thermal basis in the chalcogenide glasses.

(Received May 29, 2001; accepted June 11, 2001)

Keywords: Chalcogenide glass, Laser light recording, Electrical field recording

1. Introduction

One of the most known reversible memory effect in chalcogenide glassy semiconductors (CGS) is associated with a reversible glass-crystal phase transition. In contrast to the photo-structural effect, which is associated with a reversible structural changes between two metastable disordered glassy states [1], the glass-crystal phase transition in CGS can be initiated and reversed not only by power light but by an electrical voltage also. These facts give us a principle opportunity to combine electric field and laser light pulses for information recording processes in CGS.

The present paper is devoted to peculiarities of information recording based on glass-crystal phase transition in CGS. We discuss the differences and resemblances of the information recording by laser light and electrical voltage pulses. It is shown that recordings based on the reversible glass-crystal phase transition are similar for optical and electrical cases and the main mechanism of phase transition is determined by thermal heating.

2. Experimental details

For the optical recording investigations we have used $Te_{81}Ge_{15}As_4$ films with thickness L = 0.15-0.3 μm prepared by vacuum deposition on a glass substrate. Chalcogenide glassy semiconductors of this and similar compositions with good crystallization properties show a reversible glass-crystal phase transition and find application in electrical and optical memory cells [2]. Argon laser pulse radiation with wavelength $\lambda = 0.51$ μm, time duration $\tau = 1\text{-}0.2\ 10^{-6}$ s and power up to the 140 mW was used. The laser beam focused on the film surface created a spot with linear dimension ~5-6 μm. The result of the irradiation was controlled by measuring the transmittance of the weak probe laser light beam with $\lambda = 0.63$ μm focused on the spot, on which the recording power beam was incident, and also by subsequent inspection with transmission microscope. Two sets of samples were used for optical recording.

The first set consists of fresh, as-grown glassy films. For these films we determined the pulse power W_a and W_b needed for ~30% and ~ 60% decreasing of transparency. These values are depicted in the Fig. 1A by bars "a" and "b" and will be used for comparison with thermal induced darkening. It is known that thermal darkening originates due to shift of edge of fundamental optical absorption to the long wavelength when glass-crystal phase transition occurs [3].

The second set consists of films that have been subjected to heat treatment at the temperature ~ 540 K, which slightly exceeds the crystallization temperature ~500 K for bulk samples [4]. Full crystallization have been determined from an approximately ~ 90% decreasing in the transmission of the probe light. The onset of glass-crystal transition occurs for thin films due to thermal heating up to only ~350 K and this partly crystallized state corresponds to ~30% decreasing of transparency [5]. A level of 50-60% darkening was achieved for our CGS films by thermal heating up to temperature ~490-500 K which is approximately equals to that one for the bulk samples.

For the electrical voltage pulses recording we used the set of samples with planar geometry. The samples were thin layers of the same $Te_{81}Ge_{15}As_4$ composition, with thickness L = 0.5-1.0 μm and the area size of order 10^{-5} cm^2, which were obtained by evaporation in a vacuum onto Pyroceram substrates with electrodes width $l = 10^{-3}$ cm and gap $d = 10^{-2}$ cm between electrodes. The electrode material was a gold and a thin layer of SiO_2 was applied on CGS films for encapsulation. The as-grown glassy films were subjected to treatment at a temperature of ~500 K for 0.5-1 hour in the same manner as films from the second set used for optical recording. As a result of the treatment the films transformed into the polycrystalline state and their resistance decreased from 10^5 Ω to10^2 Ω.

3. Results and discussion

The optical recording case

For the thermally crystallized films, i.e. for the films from second set, which underwent thermal annealing at ~540 K, we determined, at different τ, the minimum pulse power W_1 needed for hole burning and pulse power W_2 which bleached the film twice as a result of reversed partial amorphization. The dependencies of $W_1(\tau)$ and $W_2(\tau)$ are shown in Fig. 1A. The most important feature of these dependencies is their closeness in the region τ> 10 μs and significant differences for τ approximately less than 1 μs. Let us estimate laser light heating temperature in the region τ> 10 μs. All τ from this region exceed the thermal relaxation time τ_r which is equal ~0.3 μs for L=0.3 μm. Then one may use a steady state approximation $W = k(T-T_0)$, where k is external heat transfer factor, T is the temperature of heated spot in a homogeneous approximation and T_0 is ambient temperature. From this we obtain $W_1/ W_a = (T_1-T_0)/(T_a-T_0)$. For hole burning the temperature T_1 must be equal or exceed the melting temperature T_m which equals to ≈ 650 K for bulk CGS under study. Then for W_1/ W_a ≈7 (see Fig. 1A) and T_0 = 300 K one obtains T_a≈350 K. This temperature is very close to the temperature 350 K needed for crystallization initiaton due to pure thermal annealing [5].

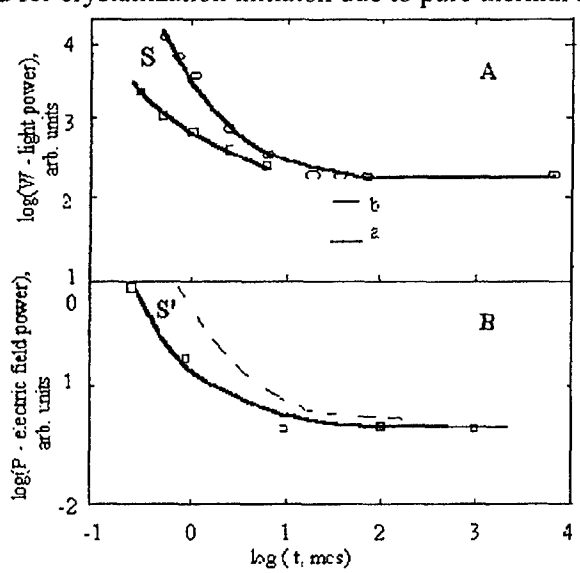

Fig. 1. Pulse power versus pulse length.
A - Laser light pulse recording for films thermally annealed at the ~540 K. The minimum hole burning power W_1 (circles) and the minimum power leading to a twofold increasing in the transmittance W_2 (squares). The horizontal bars labeled "a" and "b" correspond to a decrease in the transmittance by ~30% and ~60% from its value in non-annealed original glassy films.
B – Voltage pulse recording for films thermally annealed at ~500 K. The minimum values of electrical pulses power P (squares) leading to reverse increasing of resistance to initial value of fresh as - grown glassy films. Dashed line corresponds schematically to power leading to film destruction.

In the paper [6] it is emphasized that crystallization which is induced by short laser light pulses is not only thermal phenomenon but excess electron-hole pairs generated by light play important role. This is valid, especially for crystallization kinetics, but coincidence of temperatures needed for ~30% decreasing of transparency either by pure thermal heating or treating by 20-30 μs laser light pulses gives a strong evidence that the main part of a laser light pulse energy spends on pure heating. We have checked this conclusion by using the second bar "b" (Fig. 1A), which corresponds to ~60 % decreasing of transparency due to 20-30 μs laser light pulses. From $W_1/ W_b \approx 2$ one obtains value $T_b \approx 475$ K which is very near to the temperature ~500 K, needed for the same decreasing of transparency in the pure thermal heating case [5]. Thus, in the following we will use the simple estimation of temperature which is induced by short laser light pulses based on pure thermal approximation.

According to this approximation $W_2(\tau)$ dependence for $\tau < 1$ μs. is determined by heating to constant temperature, but in non-stationary regime because $\tau \leq \tau_r$ [7].

It is supposed that this constant temperature equals the melting temperature $T_m = 650$ K, because for "crystal-glass" phase transition this temperature is minimum needed value. The $W_1(\tau)$ dependence for $\tau < 1$ μs is governed by heating also in non-stationary regime, but to temperature considerably higher than T_m [7]. Due to the difference between $W_1(\tau)$ and $W_2(\tau)$ dependencies region S (Fig. 1A) has been revealed. All points of this region $W_1(\tau) > W > W_2(\tau)$ correspond to power W when pulses induced "crystal-glass" phase transition due to heating to temperature higher then T_m, but without film destruction.

These results demonstrate the characteristics of interaction of short laser pulses with thin films of CGS and they show that known advantages of optical recording and re-recording of information using short pulses are possibly related to the existence of a wide power region S for short times whereas this region is appreciably narrower for long times. Then it is very difficult to use appreciated value of W from the interval $W_1(\tau) > W > W_2(\tau)$ in the region $\tau > 10$ μs and it is rather easily to do in the case $\tau < 1$ μs. For this reason we can not depict $W_2(\tau)$ curve in the region $\tau > 10$ μs (Fig.1A).

The electrical recording case

For the comparison of optical and electrical recording, the minimum values of electrical pulses power $P(\tau)$, which needed for reverse increasing of resistance to initial value 10^4-10^5 Ω are depicted in Fig.1B. One can see that this dependence $P(\tau)$ is very similar to the dependence $W_2(\tau)$ of Fig. 1A. It is may be easy understood from the thermal heating point of view, because for reverse transition from crystal value resistance ~10^2 Ω to glass one 10^4-10^5 Ω the heating up to the melting temperature needed. The next interesting and important result in the electrical recording case is the following. In the region $\tau > 10$ μs, if the voltages exceed 10-20% of that ones which correspond to curve $P(\tau)$ then destruction of sample occurs. But in the region $\tau \leq 1$ μs the interval between voltages correspond to curve $P(\tau)$ and that ones, which destroyed the films are 100% and more. We have not systematically measured the destroyed voltages so the curve which is analogous to $W_1(\tau)$ dependence of Fig. 1A is depicted in Fig. 1B schematically by dash line only. But, nevertheless, one can see that region S' exists in the electrical recording case also. This region is wide for short pulse duration, whereas it is appreciably narrower for long pulse duration, as in optical recording case too.

4. Summary

The characteristics of optical and electrical recording of information based on pulse induced "crystal-glass" phase transition are very similar. Laser pulse with power W_2 has bleached locally the film due to "crystal-glass" phase transition. The powerful pulse W_1 has burned the film. It was demonstrated that for pulse with duration τ approximately less than 1 μs there is a wide pulse power interval $W_1(\tau) > W > W_2(\tau)$ or region S, when pulses induced "crystal-glass" phase transition without film destruction. The interval $W_1(\tau) - W_2(\tau)$ decreased with τ and for $\tau > 10$ μs region S became so

narrow that bleaching without destruction was very difficult to get. Similar results have been obtained when "crystal-glass" phase transition was induced by electric field pulses.

It is shown that the effect of laser light and electric field pulses on the chalcogenide materials has mainly a thermal nature.

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